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Development of an index for quick comparison of helicopter costs and benefits

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Abstract. A helicopter comparison index was developed to incorporate cost and benefit information for individual helicopters for large wildland fire suppression operations. The costs and benefits for individual helicopters are unique. Costs consist of daily availability and hourly flight rates. Benefits depend on the payload, which depends on the altitude and temperature of operation, weight of the helicopter, equipment on board, crew, and fuel. Because of the complexity of calculating payload, previous methods for deploying helicopters classified helicopters into three types according to their typical payload. The least expensive helicopter of the desired type was deployed. Because this classification system produces a broad range of benefits within each helicopter type, this method may not deploy the most efficient helicopter.

The helicopter comparison index can be calculated at representative altitudes and temperatures before it is needed. As the work is done beforehand, the helicopters can be compared quickly when they are needed. The helicopter comparison index allows helicopters to be compared based on the efficiency of the individual helicopters rather than just their cost of operation. Evaluation of Type I helicopters shows that using the helicopter comparison index instead cost of operation has savings potential of 20 to 45 percent.

Additional keywords: aircraft, aircraft contract, aircraft efficiency, cost–benefit analysis, fire suppression, fire suppression resources.

Introduction

The United States government spent approximately US$150 million on helicopters for fire suppression during 2000 (E. Stone, unpubl. data). A considerable amount of this money was spent contracting large helicopters for use on large wildland fires. One source for these helicopters is the National Call-When-Needed (CWN) contract. The CWN contract gives interagency dispatchers access to hundreds of helicopters that can be ordered if the need arises. With so many helicopters to choose from, finding the most efficient helicopter for the fire suppression situation is difficult.

Helicopters are categorised according to the typical payload for their make and model. Type I helicopters carry over 2268 kg (5000 lb) at sea level and 15°C, Type II helicopters carry between 1134 and 2268 kg (2500 and 5000 lb) at sea level and 15°C, and Type III helicopters carry less than 1134 kg (2500 lb) at sea level and 15°C (USDA Forest Service 2002). The National CWN contract is the primary source for Type I and Type II helicopters for wildland fire suppression.

Helicopters are also categorised according to their certification for hauling people. Many of the large helicopters are military surplus with restricted category certification, meaning fire suppression efforts with these helicopters is limited to tank and bucket work, and hauling cargo. These helicopters are contracted for Limited Use whereas helicopters that are certified to haul personnel are contracted for Standard Use.

Orders for helicopters for wildland fire suppression operations specify the type and certification category of the helicopter desired. The decision process for determining which National CWN helicopter to deploy evaluates helicopter availability, location, and expected cost. The lowest cost helicopter of the desired type and category located within the mobilisation limit is deployed (R. Roth, pers. comm.). Because of the wide range of payload capabilities within the helicopter type specifications, this decision method does not ensure that the most efficient helicopters are deployed.

An efficient allocation of helicopters for fire suppression can be found by evaluating the costs, benefits, and mobilisation time for the available helicopters. Because the duration of the suppression effort is unknown when helicopters are being deployed, the helicopter costs and benefits cannot be calculated directly.

Helicopter costs are a function of the contracted daily availability rate and the hourly flight rate. Helicopter benefits are directly related to the amount of weight that the helicopter can carry. This depends on the weight of the equipped helicopter and its lifting capability, which is altitude- and temperature-dependent. Thus the benefits that a helicopter can provide at a fire depend on the conditions at the fire.

Ferry costs can be readily estimated, but the reduction in efficiency due to mobilisation time depends on the contract duration. If the ferry costs are small relative to the costs incurred at the fire, the efficiency of the helicopter will be reduced minimally. Mobilisation time also decreases effectiveness by delaying the suppression effort. Mobilisation time is an important factor for consideration – not only the helicopter mobilisation time but the time required to mobilise all the personnel and equipment required for helicopter operations.

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It is not practical to estimate the efficiency of individual helicopters for a specific wildland fire. The uncertain nature of wildland fire prevents accurate knowledge of the extent of the suppression effort, so the helicopter cost and performance can only be estimated at deployment time. Estimating the performance at the altitude and temperature of operation for each helicopter is tedious. A comparison index that approximates the ratio of the cost to the amount that can be delivered provides decision makers with better information to quickly determine the most efficient helicopter.

The present paper details the development of a comparison index that can be used to compare the efficiency of helicopters at representative altitude and temperature conditions. The index was developed for deploying helicopters on the National CWN contract to large wildland fires, but it can be used in any situation where helicopters are compared based on costs and payload capabilities.

Evaluating helicopter benefits

Helicopters are versatile and effective in wildland fire suppression. They are used for a wide range of activities, such as moving people and cargo, building and supporting firelines, and reconnaissance. The helicopter fleet consists of an assortment of makes, models, and ages of helicopters with a wide range of capabilities.

As fire suppression tools, each helicopter has unique capabilities. Because of the wide range of tasks helicopters perform for fire suppression and in the private sector, they carry a variety of equipment. The weight of the equipment that allows a helicopter to perform a specific task, such as seats for hauling people, may make it less efficient at performing other tasks, like bucket work. Thus, two similar helicopters that are equipped for different tasks will have different payload capabilities.

Beyond the ability to perform specific tasks at a fire, the lifting capability of a helicopter at the fire is one limiting factor to the benefits a helicopter can provide. The lifting capability, often referred to as helicopter performance, depends on the altitude and temperature of operation. Each make and model of helicopter has its own set of performance charts developed by the manufacturer. These charts give the lifting capability of the engines at the altitude and temperature of operation (USDA Forest Service 2002). The maximum allowable payload for the helicopter at the altitude and temperature of operation is calculated using these performance values. These calculations are complicated further because fire suppression activities occur over a range of altitudes and temperature conditions, so there is not a single performance value for helicopter operations at a fire.

In order to include helicopter performance in the decision process, the performance values for a helicopter need to be generalised and put into a form that can be accessed easily. The Interagency Helicopter Approval and Performance Index (IHAPI) database was developed for the US Department of Agriculture (Forest Service) to manage the contract, performance, and inspection information for all the helicopters on the National CWN and exclusive-use contracts. The contracting and helicopter staff at National Interagency Fire Center (NIFC) maintain the information in the database. In the IHAPI database, helicopter performance is calculated at five representative altitude and temperature conditions:

- 762 m (2500 ft) and 35°C,
- 1524 m (5000 ft) and 30°C,
- 2438 m (8000 ft) and 25°C,
- 3048 m (10 000 ft) and 20°C, and
- 3658 m (12 000 ft) and 15°C.

Maximum gross weight data for these conditions are obtained from the performance charts for each make and model of helicopter on contract. The maximum allowable payload for individual helicopters is approximated by subtracting the weight of the equipped helicopter, the weight of 1.5-h worth of fuel and 91 kg (200 lb) for each pilot from the maximum gross weight. The maximum allowable payload for different helicopters of the same make and model can vary significantly because helicopters carry equipment for a variety of missions.

The benefits that a helicopter provides at a fire are the number of people hauled, pounds of cargo delivered, or the amount of water delivered to the fireline. When delivering cargo or making water drops, the load size is adjusted to fully utilise the payload capabilities of the helicopter. For hauling personnel, the number of people delivered depends on the payload capabilities and the number of seats available. Helicopters that do not have enough seats to utilise their payload capabilities are less efficient at hauling people than those with enough seats. Because payload size at the altitude and temperature of operation is the limiting factor for the benefits a helicopter can provide at a fire, it is a good measure to use for comparing helicopters. Thus, the total benefit a helicopter can provide to a fire is the maximum allowable payload (P) at the altitude and temperature of operation, multiplied by the number of loads delivered per hour (L) and the flight time in hours for working the fire (t).

$$\text{Total benefit} = P \times L \times t \tag{1}$$

Evaluating helicopter costs

National CWN helicopter bids are solicited from operators for daily availability. In addition, the government fixes an hourly flight rate based on the cost of operating the helicopter. Hourly flight rates are established for each helicopter make and model based on the costs that can be attributed to an hourly cost such as fuel. The total cost for contracted helicopters is the total flight time in hours (T), multiplied by the hourly flight rate (fr), plus the daily availability (dr), multiplied by the number of days the helicopter is on contract (d):

$$\text{Total cost} = fr \times T + dr \times d \tag{2}$$

where T includes the time required to fly the helicopter to and from the incident (USDA Forest Service 1992).

Helicopters are also placed on exclusive-use contracts. In this case, helicopters are put on contract for a set period of time and often for a particular purpose. Because operators know in advance the length of the contract, these helicopters are offered at a lower daily availability rate. By the same token, they are paid even if they are not needed. Exclusive-use helicopters are usually assigned to a particular forest for the fire season and are used primarily for initial attack.

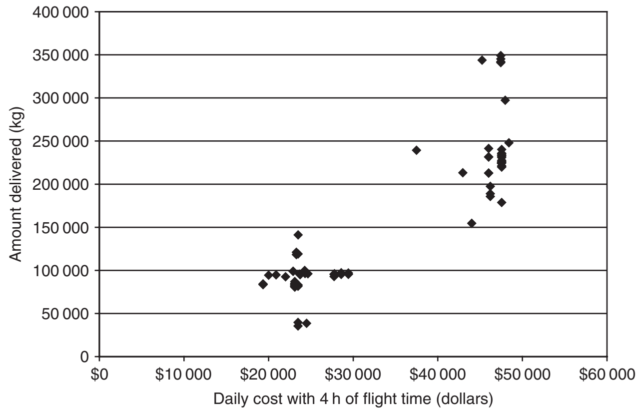

Fig. 1. Relationship between daily helicopter cost with 4 h of flight time and the amount that can be delivered assuming ten loads delivered per hour for all Type I Limited helicopters on the 2002 National Call-When-Needed (CWN) contract using data from the Interagency Helicopter Approval and Performance Index (IHAPI) database.

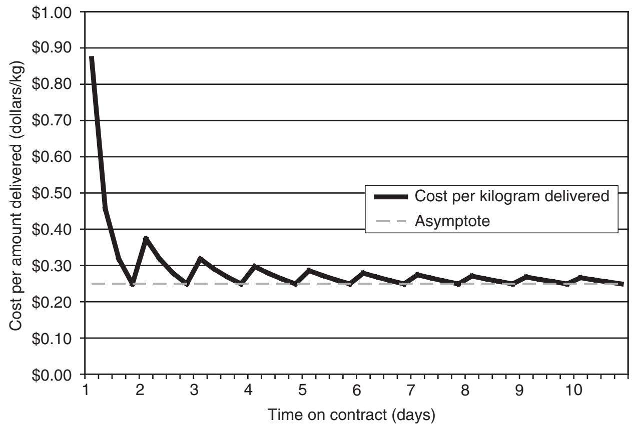

Fig. 2. Example of hourly cost per amount delivered for a Kaman KMAX helicopter operated by Superior Helicopter LLC to a fire at 1524 m (5000 ft) and 30°C over time assuming 4 h of flight time per day, ten loads delivered per hour, and no mobilisation time.

Development of a 4-h comparison index

Helicopter expenses can make up a large percentage of the total cost for a suppression effort (Mangan 2001). As suppression costs are a major concern, the cheapest helicopters of the desired type are deployed. It is easy to compare helicopter costs, but difficult to calculate estimates of helicopter performance. By considering only the costs, a significant amount of information regarding helicopter efficiency is ignored. Using cost alone for deployment decisions will not provide efficient allocations because helicopter costs and benefits are not correlated. Fig. 1 shows the relationship between cost and performance for Type I Limited helicopters on the 2002 National CWN contract. On the graph, the military and civilian versions of the heavy lifting Boeing-Vertol Chinook and Sikorsky Skycrane helicopters form a separate group because of their high cost. These are expensive helicopters built to haul heavy loads. The variability in the payloads for these helicopters is due to the equipped weight of the individual helicopters.

An alternative method for making deployment decisions is to evaluate the costs and performance for the available helicopters and deploy the helicopter with the lowest cost per amount delivered. Using performance values at 1524 m (5000 ft) and 30°C, the cost and amount delivered are calculated using Eqns 1 and 2. The graph of the cost per amount delivered as it relates to time on contract shows that the ratio is large initially and approaches a constant value, the asymptote, as the length of the contract increases (Fig. 2). The equation for the asymptote is:

$$\text{Asymptote} = (dr/h + fr)/(P \times L) \quad (3)$$

where h is the average flight time per day.

At the time of deployment, the duration of the contract is unknown. Historically, the duration of use for Type I CWN helicopters has varied from 1 to 30 days with an average of about 7 days per dispatch (USDA Forest Service 1992). As fires often occur in the same area owing to weather conditions and ignitions, CWN helicopters are often moved from fire to fire, increasing the total time on contract. With long contract times, the asymptote approximation of the cost per amount delivered provides an appropriate value to use for comparing helicopters.

The asymptote depends on two values that are unknown at deployment time – the number of loads that can be delivered in an hour (L) and the average number of hours that will be flown in a day (h). The number of loads delivered in an hour will vary with the incident but can be assumed to be the same for all helicopters being compared for the same mission. With this assumption, a comparison value for helicopters responding to the same incident can be written as:

$$\text{Comparison value} = (dr/h + fr)/P \quad (4)$$

where dr and fr are the daily availability rate and flight rate for the helicopter, P is payload at the altitude and temperature of the fire, and h is the average number of hours flown per day.

As both the fire and the weather are relatively hard to predict, it is very difficult to estimate the average number of hours per day the helicopter will fly while it is on contract. Fortunately, the comparison value with 4 h of flight time per day is linearly related to the cost per amount delivered, no matter how many hours are flown each day. Fig. 3 illustrates the relationship between the asymptote calculated using 4 h of flight time per day and the actual cost per amount delivered when the average flight time is 2 and 8 h per day for the Type I Limited helicopters on the 2002 National CWN contract, using data obtained from the IHAPI database. In every case, the correlation coefficients for the asymptote with 4 h of flight time and the actual cost per amount delivered is ~0.99. This indicates that the 4-h asymptote is proportional to the actual cost per amount delivered regardless of the actual number of hours that are flown per day. The asymptote calculated using 4 h of flight time per day provides a method for comparing the efficiency of helicopters for deployment decisions. The points that deviated furthest are newer, more efficient helicopters, which have a lower relative flight rate and higher relative daily availability than the majority of the helicopters in the fleet.

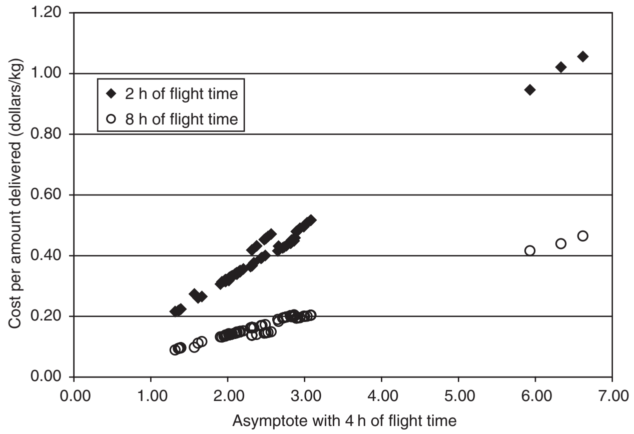

Fig. 3. The asymptote with 4 h of flight time is highly correlated with the actual cost per kilogram delivered even if the average number of hours flown per day is 2 or 8 h. Calculations use IHAPI data for helicopters on the 2002 National CWN Type I Limited contract, and assume conditions of 1524 m (5000 ft) and 30°C with ten loads delivered per hour. In each case, the correlation coefficient is greater than 0.99.

Assuming the helicopter will average 4 h of flight time per day, Eqn 4 can now be written as:

$$(dr/4 + fr)/P = 1/4 \times (dr + 4 \times fr)/P \qquad (5)$$

where dr and fr are the daily availability rate and flight rate for the helicopter and P is payload at the altitude and temperature of the fire.

By defining the 4-h comparison index to be $(dr + 4 \times fr)/P$, the index can be calculated using contract costs and the maximum allowable payload at the altitude and temperature conditions, which are know at dispatch time. When representative altitudes and temperatures are used, these calculations can be made in advance of when they are needed. The 4-h comparison index summarises the cost and performance information for individual helicopters, providing a means to easily compare the efficiency of individual helicopters. It is proportional to the approximated cost per amount delivered and can be thought of as the relative efficiency (costs *v.* benefits) for individual helicopters:

$$\text{Cost/amount delivered} = 1/4 \times \text{4-h index}/L \qquad (6)$$

where L is the number of loads delivered in an hour.

Savings estimate

The 4-h comparison index quantifies the efficiency of individual helicopters at any altitude and temperature condition. For predefined conditions, the index provides a method for quick comparison of helicopters, allowing helicopters to be deployed based on cost and performance rather than cost only. In order to determine whether the savings justify the work required to establish performance values, a theoretical analysis compares the results obtained from using the two decision methods.

The helicopters available for deployment to any fire are restricted by their ability to perform the required tasks at the fire, their availability, and their proximity to the fire. Thus, when a helicopter is to be deployed to a fire, it is selected from a subset of the helicopters on the National CWN contract. Analysis of the different possible subsets of the Type I helicopters on the 2002 National CWN contract allows for a comparison of the expected cost per amount delivered for selections made using the minimum cost *v.* those made using minimum 4-h comparison index.

The probability that a helicopter will be selected for a fire can be calculated by evaluating all the possible subsets of helicopters and all the subsets where the helicopter will be selected. The number of subsets of helicopters of a size k, if there are n helicopters on the National CWN contract, is given by:

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \qquad (7)$$

where n is the number of helicopters that could be selected and k is the number of helicopters in the subset.

A helicopter will only be deployed if all the other helicopters being considered have a larger value for the selection criteria: cost or 4-h comparison index. The number of subsets where a particular helicopter will be selected can be found by calculating the number of subsets where this is true. Let m denote the number of helicopters with a larger cost or index than the one being considered. The number of possible subsets for which this helicopter will be deployed is given by:

$$\binom{m}{k-1} = \frac{m!}{(k-1)!(m-k+1)!} \qquad (8)$$

where m is the number of helicopters that would not be selected if the helicopter being considered was in the subset of k helicopters. The probability a particular helicopter will be selected from a subset of size k is given by Eqn 8 divided by Eqn 7.

Consider the 82 Type I Limited helicopters on the 2002 National CWN contract. Because of unavailability or long mobilisation distances, only a few will be in the subset being considered for deployment to any fire. If there are five helicopters in the subset being considered, 27 285 336 different possible subsets of five helicopters can be made from the Type I Limited helicopters on the contract. For a particular helicopter to be selected, it must be the best member of the subset. If helicopter A has a lower 4-h comparison index than 68 of the 82 Type I Limited helicopters, then there are 814 385 subsets that consist of helicopter A, and four helicopters that are inferior to helicopter A. The probability that helicopter A will be selected from a random subset of five helicopters is 0.0298.

The expected efficiency for a subset of a given size is obtained by multiplying the probability that a helicopter is selected by the efficiency of the helicopter for all helicopters. Fig. 4 shows these averages for all the possible subset sizes using helicopters on the 2002 National CWN Type I Limited contract. This plot clearly shows that for all subset sizes greater than one, there is a big advantage to choosing the helicopter with the lower 4-h comparison index over the minimum cost helicopter. In fact, the percentage savings range from 20 to 45%, as shown in Fig. 5, with the most probable savings being in the range of 30 to 40%. With millions of dollars being spent annually on helicopters for fire suppression, this means substantial savings in total annual suppression costs.

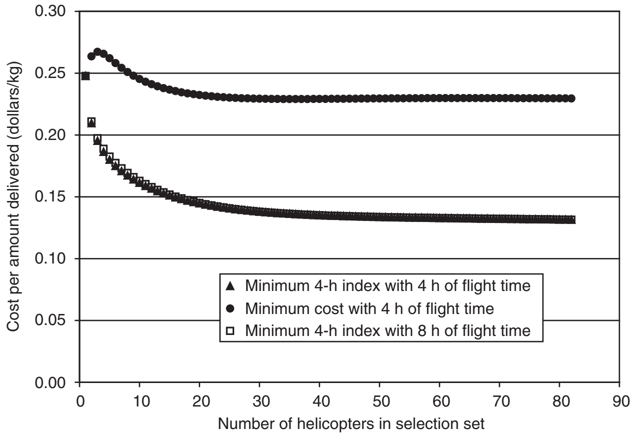

Fig. 4. Average cost per amount delivered for different-sized subsets of helicopters from the 2002 National CWN Type I Limited contract when least cost and a 4-h comparison index are used as the selection criteria. Graph developed for 1524 m (5000 ft) and 30°C with 10 loads delivered per hour. Cost and performance data obtained from IHAPI database.

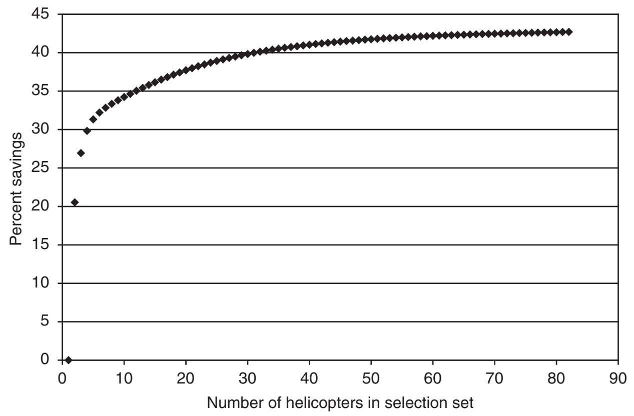

Fig. 5. Percentage difference between the average cost per amount delivered values for the choices made using the least expensive helicopter, or the helicopter with the lowest 4-h comparison index.

The earlier discussion concludes that the costs and benefits for different daily flight times are correlated; thus the 4-h comparison index can be used for making deployment decisions. An analysis similar to the one used to estimate the savings shows that when 8 h are flown per day, little is gained by using an average of 8 rather than an average of 4 h for the computation of the comparison index (Fig. 4). Hence, the assumption that there will be an average of 4 h of flight time per day has a minimal effect on the final decision.

Mobilisation times

National CWN helicopters can be located anywhere before being contracted, making the time and money needed to mobilise a helicopter an important consideration during deployment. The 4-h comparison index was generated under the assumption that only nearby helicopters are considered for deployment. This is not always the case. In many situations, the additional costs associated with mobilisation need to be included in the cost–benefit analysis. This can be done by including the costs for the ferry time associated with mobilisation. This is only one approach to the issue. It may also be desirable to add a penalty to the cost to represent the effect of delaying this facet of the suppression effort.

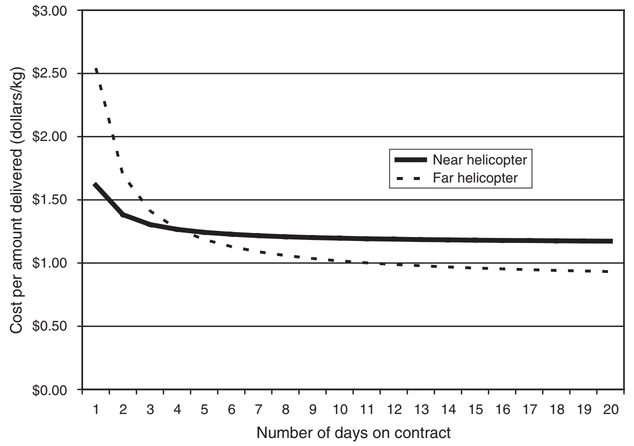

Fig. 6. Example of cost per amount delivered for two helicopters with increasing contract length. Near helicopter is within 4 h of the fire and has a 4-h comparison index of 5.22. Far helicopter requires 2 days for mobilisation and has a 4-h comparison index of 3.84. After 5 days on contract, the far helicopter is more efficient than the near helicopter.

Mobilisation time can be an important component for some allocation decisions, but the magnitude of the effect depends on other parameters in the decision-making process. When the helicopters being compared have significantly different mobilisation times, the 4-h comparison index does not provide enough information. The most efficient helicopter will be dependent on the contract length. Mobilisation costs are a fixed addition to the operating costs. As the length of the contract increases, the mobilisation costs have less of an effect on helicopter efficiency. For longer contracts, the 4-h comparison index can be used to determine the most efficient helicopter. This is because as the contract length increases, mobilisation costs have a diminishing effect on the ratio of the costs to the amount delivered. In these situations, a nearby helicopter may be more efficient in the short-term, but as time goes on it could become more expensive (Fig. 6).

Mobilisation time is an important factor for consideration when the expected contract length is short. In such cases, it is preferable to deploy nearby helicopters because the 4-h comparison index does not consider the costs of delaying the suppression effort.

Conclusion

Helicopters are a valuable, yet costly, fire suppression resource. To ensure that helicopters are deployed more efficiently, knowledge about the costs, capabilities, and performance of individual helicopters should be included in the decision-making process. The performance of individual helicopters is difficult to quantify because it requires looking up values from the helicopter’s performance charts for the specific altitude and temperature conditions at the fire. The 4-h comparison index summarises the costs and benefits of individual helicopters for representative conditions. It provides a concise means for comparing the efficiency of individual helicopters for deployment to large fires. Although calculating helicopter performance for the comparison index is not a trivial task, its use should be explored. Using the 4-h comparison index rather than cost for comparing helicopters has the potential of significant savings.

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